TMO TECHNOLOGY DEVELOPMENT PLAN

Network Signal Processing Work Area

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OBJECTIVE:
The overall objective of this work area is to identify, investigate, develop, test, and demonstrate advanced digital signal processing systems which enable the Deep Space Network (DSN) to meet its current and future requirements in an efficient, cost-effective, and reliable manner.

GOALS and SIGNIFICANCE:
This work area is focused on providing alternative options to support low-cost missions through state-of- the-art signal processing in the DSN. By using digital signal processing, systems can be constructed with greater reliability, smaller size, higher performance; thus reducing maintenance and operation cost. Improved signal processing on the ground can also enable the use of smaller, cheaper flight telecommunication systems in the future.

Advanced digital signal processing systems are now in common use, and give every indication of eventually sweeping away the time-honored analog signal processing systems now used in radio, television, and telephone. The key advantages of digital signal processing compared to the conventional analog technique are 1) high accuracy, 2) flexibility, and 3) insensitivity to the operation environment. The last is particularly important as analog components tend to drift and hence require precision tuning. For most communication applications, the physical channel is by nature analog, and thus the transmitting and receiving antennas are analog devices. However, by digitizing the receiving signal, subsequent processing can be made immune to the analog fluctuation. The recent advances in high-speed computing and VLSI fabrication and implementation technologies make digital signal processing the sensible choice for the future DSN.

Potential applications of advanced signal processing technique to DSN are:

1) signal combining and tracking from an array of feed horns on a single aperture. The array-feed compensation system combines the distributed energy at the focal plane of an antenna to compensate for the antenna’s deformations. By processing the signals from the array feed, accurate information on the spacecraft angular position can also be deduced. This information can then be used to close the pointing control loop of the antenna and, if the offset is small, can also be electronically corrected in the signal processing. Develop and demonstrate Ka-band array feed combining, tracking, and pointing concepts is a priority of the Network Signal Processing work area. Successful development of the array feed technology will enhance Ka-band reception, tracking, and pointing in DSN antennas.

2) new signal processing and analytical techniques for analyzing the performance of link performance under very weak signal conditions. Future advanced coding techniques, such as Turbo codes, offer large coding gains that will result in very low symbol energy. Carrier and symbol tracking of such low energy signal can present a serious problem. This problem is particularly serious for deep space missions where potential emergency downlink data rates can be as low as 5 bits per second. Understanding the performance of the receiver under such condition is also an important task for the network signal processing work area.

3) signal combining and processing from an array of spatially separated apertures. Arraying of smaller apertures adds flexibility to DSN scheduling and may eliminate the need for building more large aperture (70m) antennas. Fuzzy logic techniques can be applied toward efficient combining of the signals from multiple apertures.

PRODUCTS:

DESCRIPTION:

There are two work units under the Network Signal Processing Work Area:

1) Ka-band Array Feed - development and demonstration of signal processing algorithms and systems based on focal-plane arraying for closed-loop tracking of signal and compensation of antenna deformation losses at Ka-band. For FY98, the array feed system will be used to demonstrate recovery of SNR-loss and simultaneous closed-loop pointing on the 70m antenna at DSS-14. Simultaneous combining and tracking data will be collected, processed, evaluated and documented to show SNR-improvement as a function of elevation. Direct evaluation of the combined channel telemetry gain on the 70-m antenna using simultaneous X-band reference will also be performed. Potential of using the array feed for accurate pointing updates at high rates (5-20 Hz depending on the SNR) and a small mirror in front of the array for high bandwidth pointing compensation will also be demosntrated. Finally, continuous dialogue with Communications Ground Systems Section is planned to initiate the transition of the technology into implementation.

2) CCSDS Early Start - In late 1992, the Space Frequency Coordination Group (SFCG) asked CCSDS Subpanel 1E to study existing and planned modulation types for efficiently utilizing scarce frequency resources. This request was motivated by a recognition that the RF spectrum is becoming both a scarce and valuable commodity. Based on early FCC auctions, the value of the 100 MHz space research service allocation, in the 2 GHz band, was worth several times NASA's yearly budget. Initially the study was conducted in three phases using mainly computer simulations as primary tools. During phase 2 of the study, it became apparent that significant improvements in bandwidth efficiency would be achievable and the simulation results should be verified using real hardware which operates at the actual power levels for space applications.

   The work unit represents an early-start effort to prepare for the full scale development of the CCSDS (Consultative Committee for Space Data Systems) Communication Testbed Initiative that was approved by SOMO for funding from FY’99 to FY’01 during the recent POP-97 cycle. The Initiative is a 3 year effort targeted to perform detailed hardware simulation as close to a realistic environment as possible. It represents a continuation of the recently concluded CCSDS Phase 3 Efficient Modulation Study. Joint effort between NASA and DoD is expected for the Initiative. The testbed will include all modulation types identified in the Phase 3 study, as well as other types currently studied for use by international space agencies (e.g., Continuous Phase Modulation, Quadrature Amplitude Modulation, Feher-Quadrature Phase Modulation etc.). One of the objectives of this task is to secure funding for the joint testbed development at JPL.

DELIVERABLES:

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
Array Feed for 70 Meter	412-41202-0-3310	225K	60K				
CCSDS Early Start	412-41209-0-3310	100K					
Total		325K	60K				

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Array Feed Compensation for 70-meter Antenna	
WORK UNIT IN WHICH FUNDED: Array Feed, 412-41202-0-3310	
WORK AREA: Network Signal Processing	

BRIEF TECHNICAL SUMMARY:

A seven-channel Ka-band Array Feed Compensation System (AFCS) has recently been installed on the XKR-cone of the 70-meter antenna at DSS-14. On these antennas, deformations of the main reflector due to gravity, thermal gradients and wind can result in significant signal-loss (as much as 10 dB at low and high elevations), virtually disqualifying 70-meter antennas from participating in future Ka-band missions. The objective of this effort is to demonstrate the ability of the AFCS to recover losses by the application of real-time digital signal processing techniques, enabling future use of the DSN-s 70-meter antennas for Ka-band reception.

Over the past three years, the seven-channel AFCS has successfully demonstrated signal-combining and pointing/tracking concepts on the 34-meter BWG antenna at DSS-13. Although these smaller antennas are much less susceptible to large-scale deformations, combining gains of 1 - 2 dB over conventional single-horn DSN receivers have nevertheless been demonstrated. An additional benefit of the Array Feed approach is its ability to measure and correct pointing errors in real-time, without requiring additional hardware.

Having demonstrated both combining and tracking at DSS-13, the AFCS has now been installed on the 70-meter antenna at DSS-14. The cryogenic front-end, seven-channel downconverter assembly and RF mirror have been mounted on top of the XKR-cone, while the IF-BB downconverter and signal-processing assemblies have been installed in the alidade. The first track of a broadband radio source (Venus) took place on July 26-th. Data collected over an elevation range of 6 - 33 degrees during the track indicated that large, 2 - 6 dB combining gains over the central channel have been achieved. However, it was also determined that central-feed efficiency during the track was much less than expected for this antenna, implying misalignment of the RF mirror and a mismatched subreflector model. The RF alignment and subreflector model will have to be greatly improved before meaningful results can be obtained.

The general applicability of the Array Feed concept to a variety of telecommunications problems is directly related to the space-time sampling performed on the received RF fields, which allows the extraction of spatial information contained in the signal. The AFCS approach differs markedly from conventional single-horn receivers, which collect total signal power without providing separate spatial samples for processing. Applying digital signal-processing techniques to the field-samples allows the AFCS to extract the embedded pointing and combining information in real time, and use this information to improve system performance. As of today, the AFCS has successfully tracked broadband radio-sources, a fast-moving satellite with rapidly varying signal-frequency (SURFSAT) and the Ka-band beacon aboard MGS, while at the same time enhancing the signal-quality of each via optimum combining.

JUSTIFICATION AND BENEFITS:

Array Feed Compensation enables future use of the DSN's 70-meter antennas for Ka-band reception by reducing signal degradation due to gravity, wind and temperature gradients to acceptable levels, while at the same time providing accurate, phase-stable tracking. Cassini, New Millenium and Pluto Flyby missions could benefit from the availability of large 70-meter antennas with 6 dB more gain than their 34-meter counterparts over the entire track. Additionally, 34-meter antennas benefit from transparent tracking and signal-enhancement provided by state-of the-art Array Feed technology. Cost of implementing this new technology is not prohibitive: a recently completed study concluded that implementing an operational low-noise AFCS at DSS-25 for Cassini support would cost a reasonable $3.6M, including a fully operational spare.

In the past, the Array Feed Signal Processing work-unit has received extensive support from other sections in the division, namely sections 333 and 335. Support included design and fabrication of the cryogenic dewar assembly and the seven-channel downconverter; reprogramming of broadband correlators to meet AFCS signal-processing requirements; developing and testing the PC-based combining and tracking assembly; and most recently helping with the installation of the AFCS on the XKR-cone of the 70-meter antenna. Furthermore, if the Deformable Mirror

(DM) is completed and installed on XKR-cone of 70-meter antenna in FY'98, the AF front-end will be used to collect, downconvert and process signals, to perform joint compensation experiments with Sect. 333, and to evaluate additional benefits obtained by application of real-time AFCS measurements to augment the DM look-up table.

APPROACH AND PLAN:

Demonstrating the benefits of Array Feed Compensation on the 70-meter antenna will require alignment, calibration, data-gathering and analysis, and documentation of results. In addition, the narrowband signal-processing subsystem will have to be assembled and tested. Alignment is already underway, and will be completed in first quarter, FY'98, including verification of single-channel efficiency curves. Systematic data-gathering with broadband sources will commence middle of first quarter, and MGS observations should begin by the start of the second quarter. Direct demonstration of telemetry-gain, using simultaneous central-channel and combined-channel inputs to separate telemetry receivers, will start beginning of third quarter. A list of specific tasks follows:

1. Install and test narrowband signal-processing assembly (1WM, $15K)

2. Refine mirror alignment and subreflector model, verify alignment using published central-channel efficiency curve (1.5 WM - $20K)

3. Determine antenna and algorithm tracking parameters, install and test Array Feed tracking algorithm on 70-meter antenna (1 WM - $10K)

4. Broadband Radio Sources: collect statistically significant data to enable evaluation of tracking-accuracy and efficiency-improvement due to the Array Feed Compensation system at high and low elevations, and various wind conditions. Because broadband sources do not require accurate frequency-predicts or closed-loop frequency tracking, this type of data is relatively easy to obtain and is very useful for evaluating antenna efficiency. This task requires scheduling tracks at DSS-14, collecting data, and documenting results. (3 WM - $45K)

5. MGS Tracks using Narrowband Correlator: obtain statistically significant data to evaluate tracking and combining performance of AFCS using MGS Ka-band telemetry. Schedule tracks, obtain frequency-predicts, design experiments and conduct tracks, collect and analyze data, document results (3 WM - $45K)

6. Telemetry Demo using MGS: simultaneously supply central-channel and combined-channel outputs to separate receivers; demonstrate real-time combining-improvement of AFCS on telemetry SNR. This is a direct measurement of AFCS telemetry enhancement on the 70-meter antenna, including all loss effects due to pointing, gravity, wind, etc., in an operational setting. This task will require interaction with Wideband Array Feed Signal Processing development work-unit to supply BB-IF digital upconverter. (4 WM - $60K)

7. Array Feed/Deformable Mirror demo: if the Deformable Mirror (DM) is completed and installed on XKR- cone of 70-meter antenna in FY'98, then AF front-end will be used to collect, downconvert and process signals. After DM evaluation, joint compensation experiments will be conducted (with Sect. 333) to evaluate additional benefits obtained by application of real-time AFCS measurements to augment the DM look-up table. Experiment planning, data-gathering and analysis, documentation of results (2 WM - $30K)

DELIVERABLES:

Deliverables are reports evaluating and documenting AFCS performance enhancement on 70-meter antenna:

1. AFCS antenna efficiency improvement/tracking evaluation (third Quarter, FY'98)
2. AFCS telemetry SNR enhancement/tracking evaluation (fourth Quarter, FY'98)
3. Results of Array Feed/Deformable Mirror experiment (end fourth Quarter, FY'98)

RESOURCE REQUIREMENTS:

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	1.8 million	225	60		2.1 million
Workforce (WY)	15	1.5	0.5		17

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: CCSDS Communication Testbed - Early Start	
WORK UNIT IN WHICH FUNDED: CCSDS Comm Testbed, 412-41209-0-3310	
WORK AREA: Network Signal Processing	

BRIEF TECHNICAL SUMMARY:

The task is an early-start effort to prepare for the full scale development of the CCSDS (Consultative Committee for Space Data Systems) Communication Testbed Initiative that was approved by SOMO for funding from FY'99 to FY'01 during the recent POP-97 cycle. The Initiative is a 3 year effort targeted to perform detailed hardware simulation as close to a realistic environment as possible. It represents a continuation of the recently concluded CCSDS Phase 3 Efficient Modulation Study. Joint effort between NASA and DoD is expected for the Initiative. The testbed will include all modulation types identified in the Phase 3 study, as well as other types currently studied for use by international space agencies (e.g., Continuous Phase Modulation, Quadrature Amplitude Modulation, Feher-Quadrature Phase Modulation etc.). One of the objectives of this task is to secure funding for the joint testbed development at JPL.

In late 1992, the Space Frequency Coordination Group (SFCG) asked CCSDS Subpanel 1E to study existing and planned modulation types for efficiently utilizing scarce frequency resources. This request was motivated by a recognition that the RF spectrum is becoming both a scarce and valuable commodity. Based on early FCC auctions, the value of the 100 MHz space research service allocation, in the 2 GHz band, was worth several times NASA's yearly budget. Initially the study was conducted in three phases using mainly computer simulations as primary tools. During phase 2 of the study, it became apparent that significant improvements in bandwidth efficiency would be achievable and the simulation results should be verified using real hardware which operates at the actual power levels for space applications.

The Initiative is built upon three main capabilities at JPL:

- Telecommunication Development Laboratory (TDL) - This facility includes complete transmitters and receivers at S-, X-, or Ka-band for end-to-end link performance evaluations.
- Testing facility developed for narrowband terrestrial communication systems - This narrowband testing facility is able to evaluate digital demodulation algorithms distorted by various channel impairments such as, intersymbol interference, additive Gaussian noise, additive coherent interference and time-varying carrier phase.
- Communications Simulation Hierarchy Concept - A comprehensive set of computer simulation tools based on the Signal Processing Workbench (SPW) for a number of technical recommendations for the CCSDS Red Book.

JUSTIFICATION AND BENEFITS:

Efficient spectrum utilization for space communication is a major driver for the development of the CCSDS Communication Testbed Initiative. The proposed early-start effort will reduce year-to-year work year variations and smoothen the NASA funding profile for the subsequent three years. The total resource requirements for the entire Initiative remains unchanged in terms of 1997 dollars. The early-start effort will

- Ensure joint funding between NASA and DoD for the entire 3 year development cycle.
- Provide detailed architecture, infrastructure and specification of the testbed at an early stage.
- Provide incremental upgrade to the current JPL testbed facility and secure additional laboratory resources.
- Allow early JPL participation in both space and military spectral allocation and management activities.
- Extend JPL space communication expertise to other civilian and military agencies.

APPROACH AND PLAN:

The early-start effort is divided into programmatic and technical activities. The main goal of FY'98 is mainly programmatic. Listed below are activities related to this effort:

- coordinate with DoD agencies to secure funding for the 3 year joint development cycle.
- participate in CCSDS spectrum management activities.

- participate in military spectrum management activities.
- coordinate with LeRC on spectrum management activities.

DELIVERABLES:

JPL will coordinate with LeRC to deliver an integrated plan to SOMO for the Initiative starting FY'99. In addition, JPL will working with DoD and industry to secure additional funding for the testbed.

RESOURCE REQUIREMENTS:

The original estimated cost is $175K for labor and $150K for hardware procurement in FY'98. The objective was to lower the work year requirements in FY00 to approximately the same level as the preceding year and the year afterwards by moving the 1.2 work-year of labor into FY'98. The $150K procurement was also moved forward to FY'98 for early funding to smoothen the NASA funding profile. It should be noted that the resource requirements table represents only half of the total funding for the complete development of the Initiative and the Total at Completion cost in terms of 1997 dollars remains unchanged.

Upon negotiation, the funding level of the work unit was reduced to $100K. The activities under the funding will be mostly programmatic to secure future year fundings. Below is the funding profile of the unit.

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	0	100K	0		100K
Workforce (WY)	0	0.6	0		0.6